What the LHC can and cannot measure in the Higgs sector and beyond

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Higgs retreat at Argonne

Disclaimer

- The talk is focused on the future prospects for the ATLAS experiment at the LHC

- CMS, LHCb, and ALICE are not mentioned in the talk.

References

- “Physics at a High-Luminosity LHC with ATLAS”; August 10, 2012; ATL-PHYS-PUB-2012-001
- Expect an updated version later this year.

- All the shown results are current (August-September 2012)

LHC schedule

- Late 2009 → Started with √s=900 GeV (after the accident in 2009)
- 2010-2011 → √s=7 TeV, Int. luminosity ~ 5 fb^{-1}
- 2012 → √s=8 TeV, Integrated luminosity ~ 22 fb^{-1} (beyond expectations)
  - Higgs discovery in the summer of 2012 included H→WW, H→WW→4ℓ, H→γγ, H→ττ, and H→bbbar (only the first three used data from 2012)
  - Instantaneous luminosities up to $8 \cdot 10^{33}$ $cm^{-2}s^{-1}$
- 2013-2014 → Shutdown (LS1 a.k.a. Long Shutdown 1)
- 2015-2017 → √s=13-14 TeV, Integrated luminosity ~ 100 fb^{-1}
  - Instantaneous luminosity ~ 10^{34} $cm^{-2}s^{-1}$
- 2018 → Shutdown (LS2)
- 2019-2021 → → √s=13-14 TeV, Integrated luminosity 200-300 fb^{-1}
  - Instantaneous luminosity doubled (crab cavities, lower beam emittances, etc)
- 2022-2023 → LS3 (preparation for the HL-LHC)
- 2024-… → √s=13-14 TeV, Integrated luminosity ~3000 fb^{-1}
  - Instantaneous luminosity ~ $5 \cdot 10^{34}$ $cm^{-2}s^{-1}$ (140 events in every bunch crossing)

Decay channels considered for Higgs

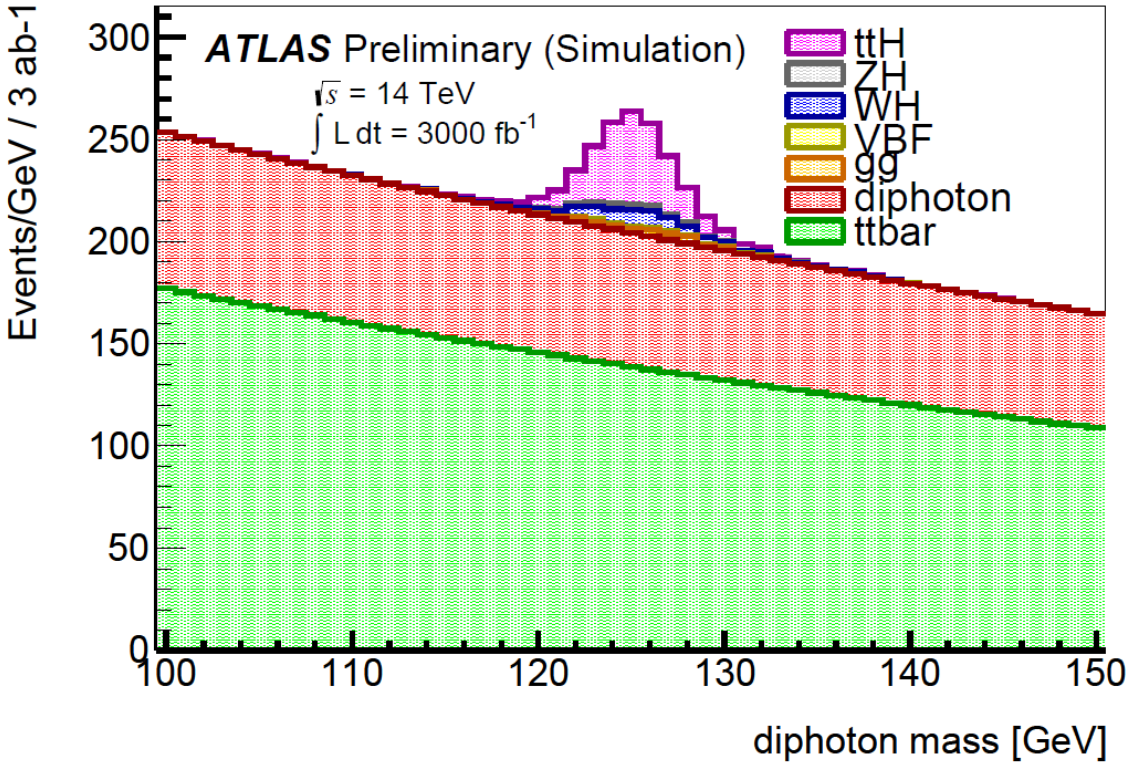
- pp → H → ZZ → 4 leptons (used for spin/CP and couplings)
  - Super clean, fully reconstructed FS, pileup is not a problem
  - scales well with higher instantaneous luminosities (pileup)
- pp → H → γγ, "0-jet"
  - Large irreducible backgrounds but the m(γγ) is sharp
  - scales well with higher instantaneous luminosities
- pp → H+2jets → γγ+2jets, "2-jet" VBF
  - Resolution of m(γγ) does not depend on pileup much. However, large rate of forward jets from pileup, indistinguishable from the hard-scatter jets
  - A bit more difficult at high instantaneous luminosities
- pp → H → WW* → 2leptons+2neutrinos (0-jet)
  - Large irreducible backgrounds from pp→WW, ttbar, and Z+jets
  - Needs good reconstruction of the missing transverse momentum
  - Gets a bit more difficult at higher instantaneous luminosities

Decay channels considered for Higgs

- pp → H +2jets → WW* +2jets → 2leptons+2neutrinos +2jets; VBF
  - Large irreducible backgrounds from ttbar
  - Needs good reconstruction of the missing transverse momentum and forward jets (almost indistinguishable jets from pileup)
  - Gets a more difficult at higher instantaneous luminosities
- pp → H → ττ (variety of decay modes)
  - Requires very good reconstruction of the missing transverse momentum
  - Large backgrounds
  - Higher pileup does not help
- pp → H +2jets → ττ +2jets; VBF
  - Same story.. A bit more difficult
- pp → WH/ZH, H→γγ, Z→ℓℓ, W→ℓν
  - Low signal rate; expect ~100 events at HL-LHC
  - S/B ~10% for ZH and 2% for WH

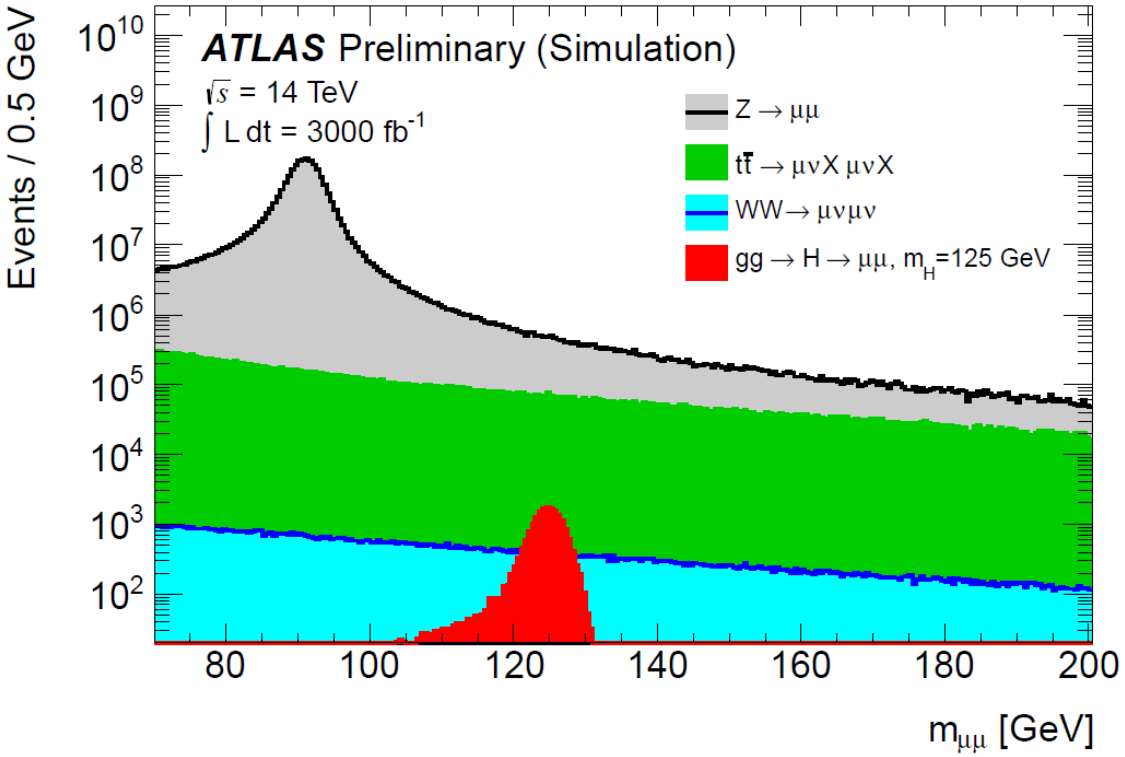
Decay channels considered for Higgs

- pp → ttbar H, H→γγ
  - S/B ~ 20%; expect ~100 events at HL-LHC
  - Precise measurement of the top-Yukawa coupling



Decay channels considered for Higgs

- pp → H →μμ
  - S/B ~ 0.2%; very narrow peak
  - 6σ from 3000 fb^{-1} from HL-LHC
  - Mostly independent of pileup

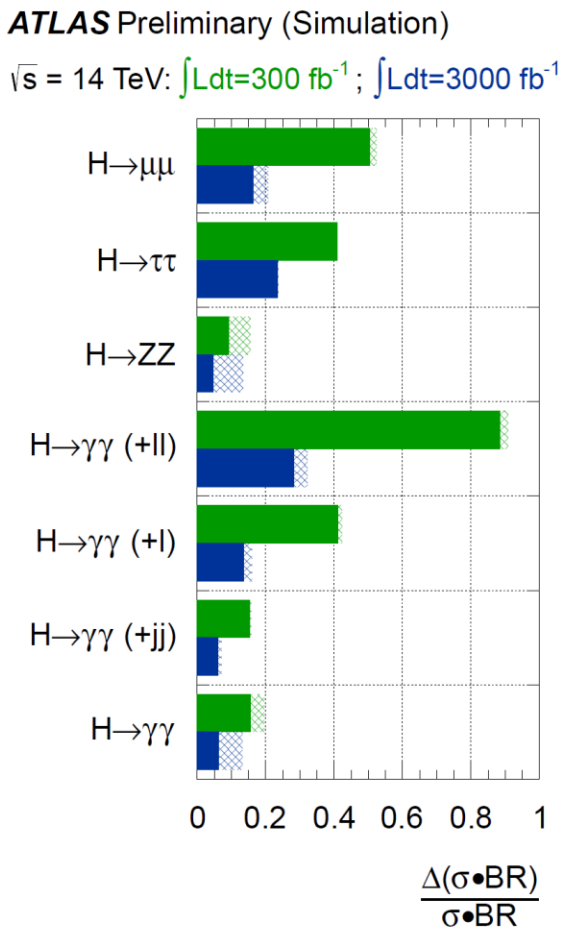


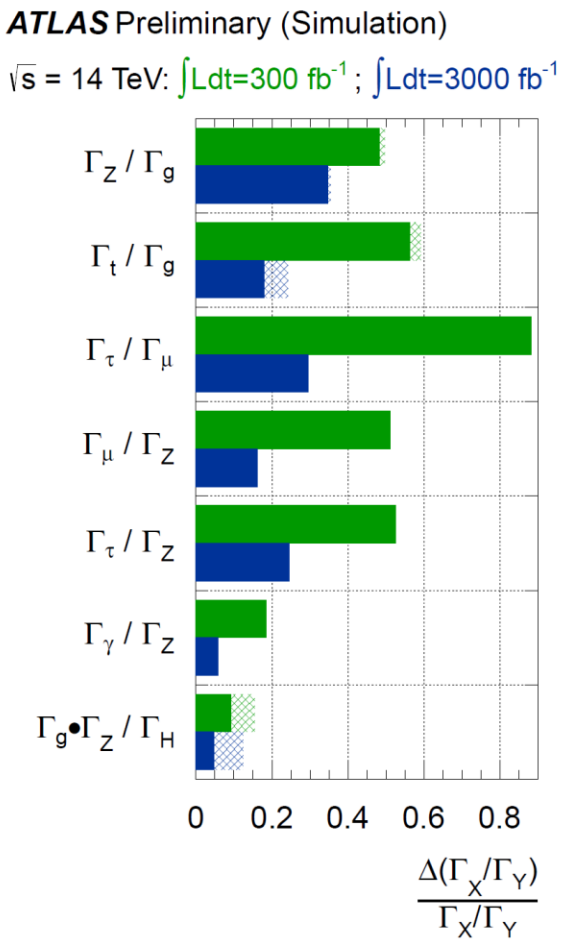
Decay channels considered for Higgs

- pp → ttbar H, H→μμ
  - Expect ~30 events from 3 ab^{-1}, S/B > 1
- pp → WH /ZH, H→bbbar, W→ℓν, Z→ℓℓ/νν (Not included)
  - High backgrounds from V+jets and ttbar
  - The jet momentum resolution degrades with pileup
- pp → WH, H→WW (3-lepton FS)
  - Sensitive to the H—WW coupling from both initial and final states
- Also expect inclusion of additional initial and final states relevant to Higgs production (e.g. pp→ZH, H→ZZ) some time later (next year)
- H→Zγ is another interesting channel worth considering..

Expected measurement precision

- No theory assumption on the particle content in the Higgs loops or the total width. Dashed bars – theory uncertainties from scales and PDFs



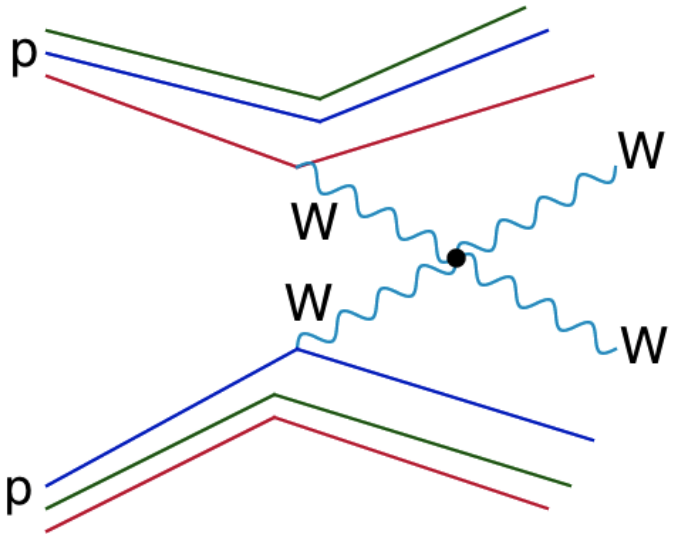


Higgs self coupling

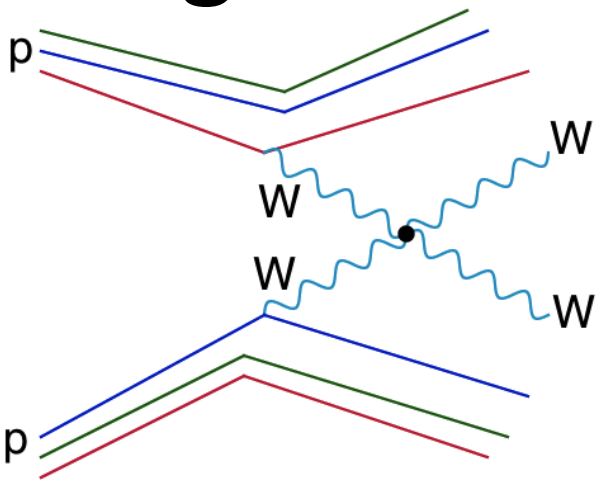
- λ_{HHH} can be measured via pp→HH pair production
  - 34 fb
  - Interferes with regular gg→HH
- Investigated two channels:
- HH→bbbar γγ
  - 260 events in the 3 ab^{-1} (before event selection)
  - S/B ~ 0.7 after event selection; 15 signal events
- HH→bbar WW
  - 25k expected events in the 3 ab^{-1}
  - almost identical to ttbar: S/B ~ 10^{-5}
- Can obtain first evidence of Higgs self coupling with HL-LHC
- More channels will be considered
- The quartic self coupling is not accessible at the LHC!

Weak boson scattering

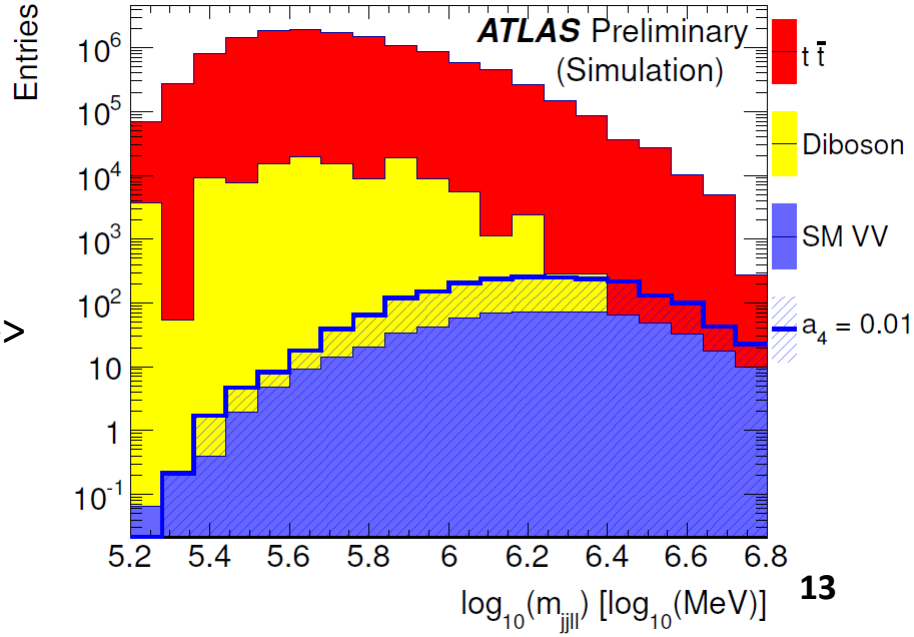
- Higgs → Expect unitarity of scattering amplitudes in longitudinal vector boson scattering
- ZZjj→4leptons +2 jets
  - Clean channel; small cross section
- WZ+2jets is also doable
  - Clean. Higher cross-sections
- WW+2jets



Weak boson scattering



- Higgs → Expect unitarity of scattering amplitudes in longitudinal vector boson scattering
- ZZjj→4leptons +2 jets
  - Clean channel; small cross section
- WZ+2jets is also doable
  - Clean. Higher cross-sections
- WW+2jets
  - Doable in for same-sign W's
  - High backgrounds for oppositely-charged W's (the fig. is for 3 ab^{-1}) --->



Conclusions

- The m(H)=126 GeV allows access to a wide variety of decay modes
- HL-LHC offer an improvement of the couplings (and rare decay modes), needed for the self-coupling
- Combination with CMS will also improve precision of the measurements